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[The origin of sdB stars (II)] The Origin of Subdwarf B Stars (II)

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abstract We have carried out a detailed binary populations synthesis (BPS) study of the formation of subdwarf B (sdB) stars and related objects (sdO, sdOB stars) using the latest version of the BPS code developed by Han et al. (1994, 1995a, 1995b, 1998, 2001). We systematically investigate the importance of the five main evolutionary channels in which the sdB stars form after one or two common-envelope (CE) phases, one or two phases of stable Roche-lobe overflow (RLOF) or as the result of the merger of two helium white dwarfs (WD) (see Han et al. 2002, Paper I). Our best BPS model can satisfactorily explain the main observational characteristics of sdB stars, in particular their distributions in the orbital period – minimum companion mass ($\log P$ - $M_{\rm comp}$) diagram and in the effective temperature – surface gravity ($T_{\rm eff}$ - $\log g$) diagram, their distributions of orbital period, $\log(g\theta^4)$ ($\theta = 5040\,{\rm K}/T_{\rm eff}$) and mass function, their binary fraction and the fraction of sdB binaries with WD companions, their birthrates and their space density. We obtain a Galactic formation rate for sdB stars of $0.014 -- 0.063\,{\rm yr}^{-1}$ with a best estimate of $\sim 0.05\,{\rm yr}^{-1}$ and a total number in the Galaxy of $2.4 -- 9.5\ \times 10^6$ with a best estimate of $\sim 6 \times 10^6$; half of these may be missing in observational surveys due to selection effects. The intrinsic binary fraction is 76 to 89 percent, although the observed frequency may be substantially lower due to the selection effects. The first CE ejection channel, the first stable RLOF channel and the merger channel are intrinsically the most important channels, although observational selection effects tend to increase the relative importance of the second CE ejection and merger channels. We also predict a distribution of masses for sdB stars that is wider than is commonly assumed and that some sdB stars have companions of spectral type as early as B. The percentage of A type stars with sdB companions can in principle be used to constrain some of the important parameters in the binary evolution model. We conclude that (a) the first RLOF phase needs to be more stable than is commonly assumed, either because the critical mass ratio $q_{\rm crit}$ for dynamical mass transfer is higher or because of tidally enhanced stellar wind mass loss; (b) mass transfer in the first stable RLOF phase is non-conservative, and the mass lost from the system takes away a specific angular momentum similar to that of the system; (c) common-envelope ejection is very efficient.